THE EFFECT OF REFLECTORS AND DELAMPING UPON LIGHT LEVELS

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ABSTRACT

In the 1987 Georgia Institutional Conservation Program (ICP), recommendations for installation of reflectors in fluorescent fixtures accompanied by delamping totaled $5.4 million. Concerned with the effects of these recommendations on light levels, the Governor's Office of Energy Resources asked the Georgia Tech Research Institute to quantify the change in light levels. This paper summarizes the study and its findings, and suggests what conditions favor the use of reflectors.

The study found that installing specular reflectors in fluorescent fixtures accompanied by 50 percent delamping resulted in reduced light levels of 60 to 80 percent of design light levels. The continuous row fixtures in the study showed the greatest variation in light levels ranging from 52 percent between rows to 80 percent under rows for an average of nearly 70 percent. Light levels in rooms with fixtures on an even grid spacing ranged from 73 percent between fixtures to 86 percent under fixtures for room averages of 75 to 80 percent. Reflectors in rooms with higher ceilings gave more uniform light distributions but resulted in slightly lower average light levels. The study concluded that fluorescent fixture reflectors accompanied by delamping is a viable means to reduce lighting energy consumption if a reduction in design light levels is acceptable.

BACKGROUND

Fluorescent fixture reflectors increase light output from a given fixture by two means. First, the reflector is specifically designed to direct more light to the work surface than are standard fixtures. Secondly, specular reflectors have a somewhat higher surface reflectivity than painted fixtures.

When fluorescent fixture reflectors were first introduced, vendors and manufacturers' representatives claimed they could maintain or increase light levels while reducing energy consumption by 50 percent. The energy savings was accomplished by removing half of the lamps and disconnecting half of the ballasts. Four-lamp fixtures were reduced to two lamps. One lamp was removed from two-lamp strip fixtures and one ballast was wired between two fixtures. The reflector vendors and manufacturers' representatives had documented field studies to support their claims. An integral part of the sales program was to measure as-found light levels and compare them to the light levels obtained after the reflectors had been installed.

Fixture manufacturers and lighting engineers raised questions about these claims. Most commercial fixtures direct 55 to 75 percent of the light from the fluorescent lamps to the work plane. For equal illumination levels to be maintained with half of the lamps removed would require that the fixture efficiency be increased to over 100 percent! It was speculated that the reflector vendors and representatives were taking credit for light level increases due to cleaning or replacing the lens covers and installing new lamps. Further questions were also raised about the durability of the reflectors (especially the film types prone to delamination and bubbling in solar applications) and the effect that cleaning (and the associated scratches) would have upon reflectivity.

Under the Institutional Conservation Program (ICP), which provides energy audits and grants to implement energy conservation measures in schools and hospitals, specular reflectors were recommended frequently as a means to reduce fluorescent lighting energy consumption. In 1987, $5.4 million worth of reflectors were recommended for installation in Georgia schools. Because of the magnitude of the reflector recommendations and the uncertainty of their effect upon light levels, the Energy Resources Group of the Georgia Tech Research Institute was asked to conduct light level measurements in four representative classrooms.

Prior to the 1987 Georgia ICP, all known studies that attempted to compare light levels were performing the comparison on unequal bases. A testing method to determine the actual effects of fluorescent fixture reflectors, screening out such variables as new lamps and cleaned lenses, was devised and is detailed in the next section of this report. Only reflective film (specular) reflectors were studied. The test method was prepared with the assistance of reflector, lamp and fixture manufacturers.

The testing was conducted in four classrooms on two campuses, two at Beulah Elementary School in Douglasville, Georgia, and two at Augusta College in Augusta, Georgia. The campuses were selected because reflector installations had been recommended for both of them under the ICP program. The classrooms were selected as being representative of classrooms on the respective campuses. The reflectors installed in this study were specifically designed by the reflector

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manufacturers to obtain optimal performance from the fixtures present in each classroom.

TEST DETAILS

Scope of Test

Three tests were selected to show the relative effect of reflectors on light levels:

Test 1: Light level with existing lamps and fixtures (as-found condition).

Test 2: Light level with new lamps and cleaned fixtures.

Test 3: Light level with 50 percent delamp and reflectors.

Testing varied from this format only slightly. One classroom at Beulah School had already been delamped prior to this study and, therefore, a light level measurement of the room with as-found, fully-lamped fixtures was not made. At Augusta College, intermediate measurements were made between Test 1 and Test 2 to determine what effect cleaning alone could have on light levels. These tests, which are in addition to the three mentioned above, are described below in "Test Results."

Test Design

During any field test, it is important to minimize the effect of variables upon the test results. Following are potential sources of error and the actions taken to minimize their effect upon the test. The test protocol was designed to take these factors into account.

Extraneous Light. Interference of exterior light through windows and doors may significantly increase or even overpower interior light levels. Action: All light level tests were conducted at night and other light sources that might influence the test were turned off or blocked out.

Steady-State Temperature of Ballast and Lamp. From the time a lamp is turned on until it reaches a steady-state temperature, the light output can vary by 15 percent. Action: Room lights were turned on four hours prior to testing to allow fixture temperature to stabilize.

Temperature of Room. Room temperature can affect the light output by five to ten percent. Action: Room temperature was taken before, during and after light-level tests. A major fluctuation would require repeating the test.

New Lamps. Light output during the first 100 hours of a new lamp declines rapidly. Typically, a five percent decrease in light level is observed. Action: New lamps were burned continuously after installation for a minimum of 100 hours before readings were taken.

Repeatability. A six-inch difference in measuring location and height may result in a ten percent variation in light level. Action: In each room, a standard surface was chosen from which to take readings. The meter was aligned on this surface under a mark on the ceiling by use of a plumb-bob. In Room A-4, measurements were made from the same corner of the immovable student desks.

Meter Calibration Errors. Variations in light levels of up to 50 percent were noted between meters by the same manufacturer. This meter is widely used by energy engineers. More sophisticated meters have much better repeatability and accuracy. Action: One meter was used to make all measurements and a second meter was used to verify consistency. Both meters were laboratory quality with high repeatability and accuracy.

Variation in Lamp Lighting Output. Variations in light output between lamps of one manufacturer of up to 25 percent have been noted. Action: This potential problem was recognized but little could be done about it between Test 1 and Test 2 where old lamps were replaced by new lamps. The new lamps used in Test 2 and Test 3 were marked and reinstalled in the same locations and with the same orientation.

Voltage Fluctuations. Two-thirds of one percent change in light output per voltage variance of one percent is typical. Action: Voltage was continuously measured during the test in one room at both schools and spot checks were made in all rooms. Significant voltage fluctuations were noted and testing was suspended if the fluctuation was greater than several percentage points.

Orientation of Lamp. Reversing the direction of the lamp in the fixture or turning the "top side down" may result in a variance in light output. Action: The new lamps were marked with a grease pen. The marked end remained facing a preselected side of the room and downward. The lamps were also marked left and right.

Reflectivity of Walls. The reflectivity of the walls will vary with displays and decorations and may cause small variations in light level. Floors and ceilings were not a factor because desks were removed from the rooms when possible and no changes were made to the ceilings. Action: Lighting measurements were made during relatively short periods (one to two weeks) to reduce the chances of major changes in bulletin board displays.

Measurement Grid

The measurement grid was selected to indicate relative room light levels rather than average room light levels. Measurement points were selected at easily identifiable points such as ceiling joints and centers of lighting fixtures. As a result, the averages of all light level measurements in a given room is not indicative of the average light level of the room as prescribed by the Illuminating Engineering Society (IES). The employed measurement grid does include enough data points evenly distributed through the test rooms to allow accurate comparison of relative light level changes within the test rooms.

Room Descriptions

Room 103, Beulah School. The physical dimensions of Room 103 appear in Figure 1A. The fixtures were two-lamp pendant types, suspended from the ceiling in continuous rows, with diffusers covering the lamps. The fixtures were relatively shallow and lower-cost, lower-quality types. Both the lamps and the ballasts were energy-efficient varieties.

Room 119, Beulah School. The room dimensions and fixture layout are shown in Figure 2A. The fixtures were four-lamp, lay-in types, located in continuous rows and enclosed with diffusers. Half of the lamps had been removed prior to the test. The fixtures were about average in depth and were lower cost, lower quality types. Both the lamps and the ballasts were energy-efficient varieties.

Room A-4, Augusta College. This room is a lecture hall, seating 120 persons. The floor slopes and the walls taper toward the front of the room. The room dimensions are given in Figure 3A. Fixtures were four-lamp types, flush-mounted on a typical grid spacing of 8'x 6' and enclosed with diffusers. Three fixtures were not functioning during the tests, two in the half of the room which was measured. The fixtures were relatively deep and of the lower-cost type. There was a mixture of energy-efficient and standard lamps and ballasts installed in the fixtures, but the overwhelming majority were energy-efficient.

Room 22, Augusta College. This was a standard-size college classroom. The dimensions are given in Figure 4A. Fixtures were four-lamp, lay-in types with a 8'x 6'grid spacing and enclosed with diffusers. The fixtures were relatively deep and of the lower-cost type. There was a mixture of energy-efficient and standard lamps and ballasts installed in the fixtures, but the majority were energy-efficient.

TEST RESULTS

The following summarizes the lighting tests by room. The lighting test protocol was followed exactly except as noted below. Under "Results," as-found light levels are compared to cleaned, relamped fixture light levels. Cleaned, relamped fixture light levels are compared to delamped fixtures with reflectors.

Another factor, the "light distribution ratio," compares the relative brightness of the measured light level beneath fixtures (max/avg) with that measured between fixtures and along the walls (min/avg). Because reflectors were said to concentrate light beneath the fixtures, this ratio was developed to indicate the degree of concentration. Uneven light distribution in a room is undesirable. The greater the increase in the light distribution ratio, the greater the increase in the light concentration beneath the fixture.

The three-dimensional graphs shown in Figures 1 through 4 depict relative light levels. The X and Y axes depict the dimensions of the measured half of the room. The Z axis is the measured light level expressed in footcandles.

The Georgia Department of Education requires 70 footcandles of illumination in new construction. After the grants for the 1987 ICP were awarded, the Department of Education extended this minimum light level rule to all retrofit lighting projects. Note that the reflector recommendations for the 1987 grant cycle were made before this rule was in effect.

Room 103

Summary. Before each test, all the desks were moved into the hall. A representative desk was chosen on which to place the light meter. The meter and desk were aligned under the grid points by a plumb-bob.

The tests were conducted according to the protocol without any modifications or aberrations. Temperatures and voltages for all readings varied by plus or minus two percent.

Results. In the as-found condition, the average light level measurement equaled 33 footcandles. When the fixtures were cleaned and relamped, the light level measurements increased by 18 to 25 percent, depending on the location of the measurement, to an average of 40 footcandles. When the fixtures were delamped and reflectors were installed, the measured light level decreased to 52 to 70 percent of the cleaned, relamped fixture light level. The average of all measurements after this step was 26 footcandles. Clearly, the light level in the room never sufficiently met the Department of Education's illumination guidelines.

The higher light levels were measured under fixtures and the lower levels were recorded between fixtures and along the walls. Delamping and installing reflectors increased the average light distribution ratio from 1.63 to 1.95 as compared to fixtures which had been cleaned with new lamps installed. Room 103 did not appear to be a good candidate for reflectors because the light distribution ratio was already large and room light levels were already very low. Figures 1B through 1D depict the light level intensity distributions for the room under the various lighting conditions.

Room 119

Summary. This room had mainly tables and chairs with only a few desks. The locations of the larger tables were marked and the tables were maintained in the same position for the duration of the tests. Chairs were stacked on the side of the room not involved in the testing, leaving the classroom open except for several large tables. One of the desks held the light meter and, where possible, was moved around the room with it. The meter was transferred onto the large tables instead of moving them to take readings. This did not have any effect on the accuracy or validity of the light-level measurements. In all cases, the height of the light meter remained constant.

FIGURE 1. DIMENSIONS AND LIGHT DISTRIBUTIONS FOR ROOM 103

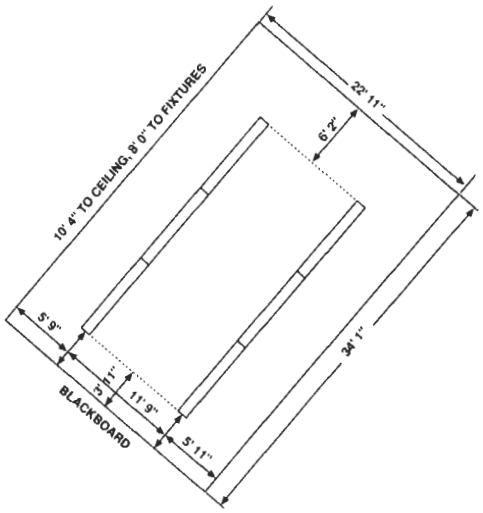

FIGURE 1A. DIMENSIONS OF ROOM 103

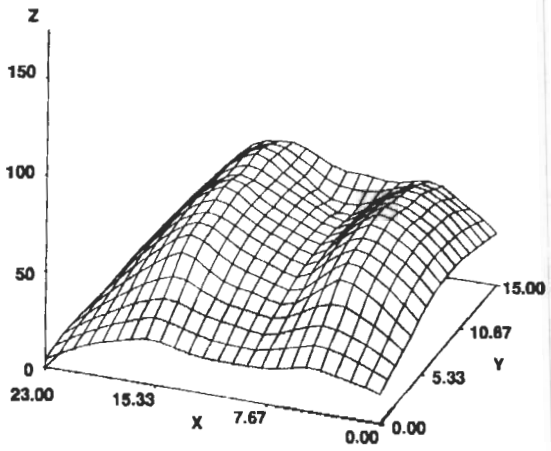

FIGURE 1C. CLEAN FIXTURES AND NEW LAMPS
AVERAGE OF LIGHT LEVEL READINGS: 40.1

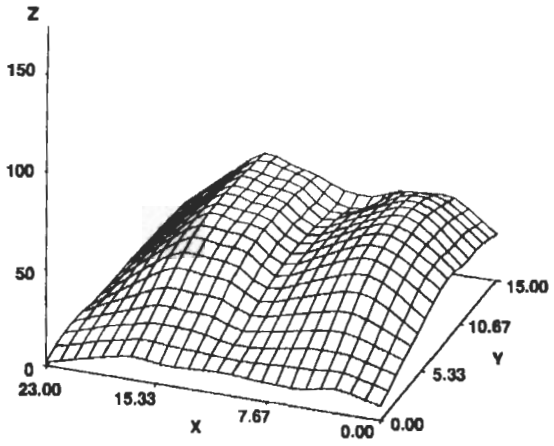

FIGURE 1B. AS-FOUND LIGHT LEVEL DISTRIBUTION
AVERAGE OF LIGHT LEVEL READINGS: 32.8

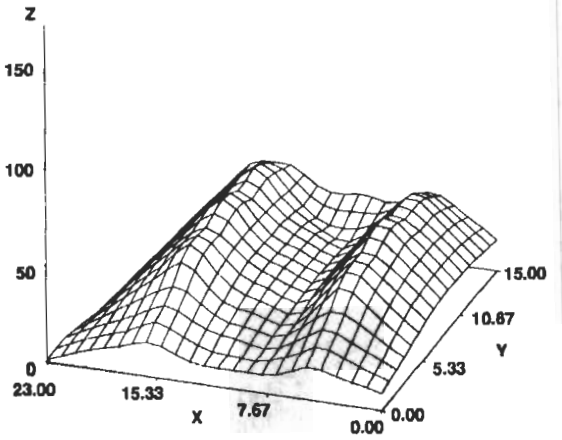

FIGURE 1D. DELAMPED AND REFLECTORS
AVERAGE OF LIGHT LEVEL READINGS: 25.8

Because Room 119 had been delamped prior to the test measurements, a fourth test was performed in addition to the three light-level measurements mentioned above. The fourth test, occurring between Test 2 and Test 3, measured the light level of clean, fully-lamped fixtures.

Voltage and temperature varied by plus or minus 2 percent during the testing periods.

Results. After cleaning and installing new lamps (but not fully lamping), the light level increased by 12 to 16 percent, depending on the location of the reading, from an average measurement of 43 footcandles to an average of 49 footcandles. Reflectors accompanied by delamping provided 58 to 80 percent of the light level of the cleaned, fully-lamped fixtures, a decrease from a measured average of 95 footcandles to 64 footcandles.

As with Room 103, light levels were greater below fixtures than between them and along the walls. Delamping and installing reflectors increased the average light distribution ratio from 2.05 to 2.80 as compared to fixtures which had been cleaned with new lamps installed. The original light levels prior to delamping would seem to favor reflectors, but because the room was already delamped and because of the large light distribution ratio, this room should not have been considered for reflectors. The light level intensity distribution for the various lighting conditions in the room is shown in Figures 2B through 2D.

Room A-4

Summary. The desks in Room A-4 were immovable and the floor sloped toward the front of the room. Light-level readings were taken from the top left corner of all the desks in one half of the room. Room A-4 varied from the preceding two rooms in that the fixtures were not laid out in rows but evenly distributed over the room.

During the third test, voltage changed significantly and affected light levels. When the light levels returned to their previous readings, voltage remained somewhat higher. An attempt was made to determine the cause of light level fluctuations but even conversations with the electric utility revealed nothing. For both the third and fourth tests, a control light source was frequently remeasured to ensure reliable data.

Temperature varied during and between the tests by not more than plus or minus 3.4 percent. Voltage varied by plus or minus four percent.

Results. Cleaning the lamps, fixtures and lenses resulted in an average light level increase of five percent, from 102 to 107 footcandles. Relamping increased average light levels another 10 percent, to 118 footcandles. Reflectors and delamping resulted in an average light level of 75 percent of the cleaned, relamped fixture light level, reducing the average light level from 118 to 89 footcandles.

The light distribution ratio increased from 1.01 after the fixtures were cleaned and new lamps installed to 1.09 when reflectors were installed and the fixtures were delamped. Because of the initial light levels and the evenly spaced fixtures, this room was an ideal candidate for reflectors. Figures 3B through 3E give the light level intensity distribution for the room under the various lighting conditions.

Room 22

Summary. The tables and chairs were all moved to one side of the room prior to taking measurements. One table was selected on which to locate the light meter. The meter was aligned below the ceiling grid using a plumb-bob.

Like Room A-4, the fixtures in Room 22 were evenly distributed and rather than in rows. Although measurements were made during the save evening, the voltage fluctuations experienced in Room A-4 were not evidenced in Room 22. Voltage remained relatively constant, varying by less than plus or minus one percent. Temperature varied by plus or minus five percent between the four tests.

Results. Cleaning the lamps, fixtures and lenses resulted in light level increases of less than one percent, with average light-level measurements increasing from 69 to 70 footcandles. Relamping increased average light levels to 81 footcandles, an increase of 16 percent. Reflectors and delamping provided an average of 80 percent of the cleaned, relamped fixture light level, a reduction in average light level to 65 footcandles. Using standard efficiency lamps instead of energy-efficient lamps would probably increase light levels to 70 footcandles, making this an acceptable installation.

The light distribution ratio was increased from 1.02 to 1.15 between the test with cleaned fixtures and new lamps to the test with reflectors and delamping. While not distracting, this increase in the light distribution ratio was noticeable. Figures 4B through 4E show the light intensity distribution for the various lighting conditions in the room.

VARIABLES AND CONSIDERATIONS

While it was the author's intent to minimize the effects of as many variables as possible, certain other variables and considerations may limit the ability to generalize from the conclusions of this paper. These variables and considerations follow.

Visual Comfort Probability (VCP) Index. Relative light levels will not necessarily indicate the acceptability of a given lighting system. The VCP was not measured as part of this test series.

Underwriters Laboratory (UL) Rating. Modification of fixtures by the installation of reflectors may void the UL listing of the fixture. This, in turn, may affect the terms of the building insurance policy.

FIGURE 2. DIMENSIONS AND LIGHT DISTRIBUTIONS FOR ROOM 119

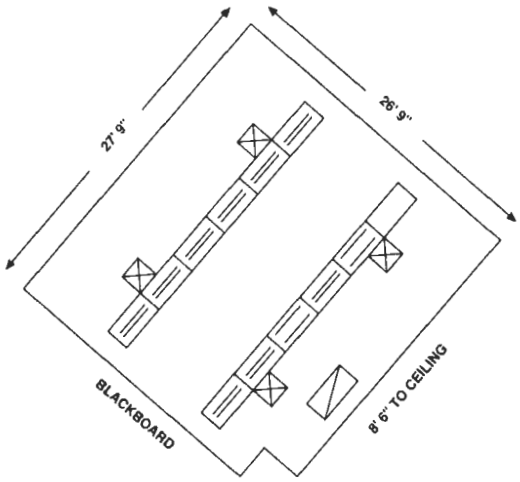

FIGURE 2A. DIMENSIONS OF ROOM 119

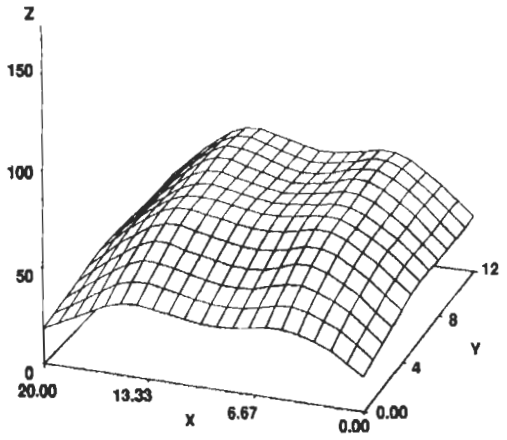

FIGURE 2B. AS-FOUND LIGHT LEVEL DISTRIBUTION
AVERAGE OF LIGHT LEVEL READINGS: 42.9

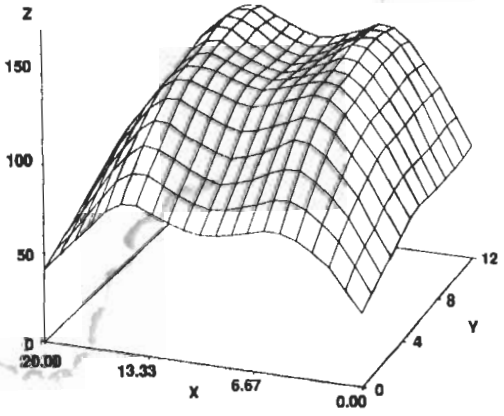

FIGURE 2C. CLEAN FIXTURES, NEW LAMPS,
FULLY LAMPED FIXTURE
AVERAGE OF LIGHT LEVEL READINGS: 94.8

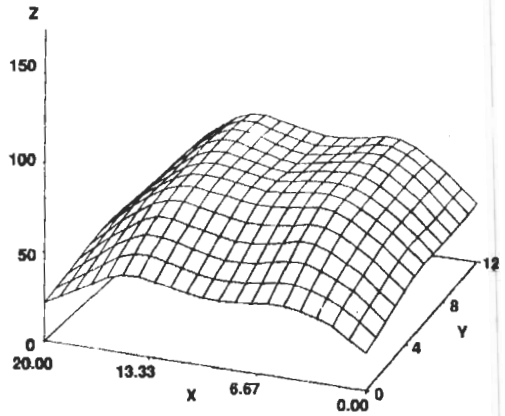

FIGURE 2D. CLEANED FIXTURES,
NEW LAMPS, DELAMPED
AVERAGE OF LIGHT LEVEL READINGS: 49.0

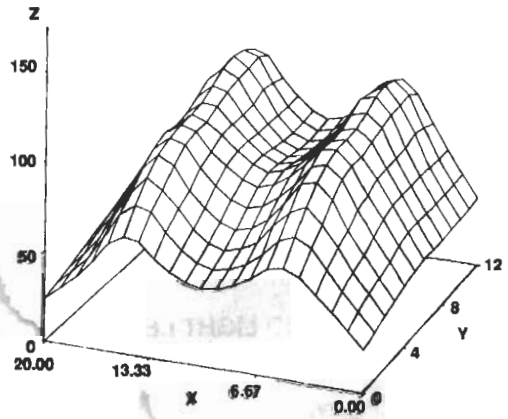

FIGURE 2E. DELAMPED AND REFLECTORS
AVERAGE OF LIGHT LEVEL READINGS: 64.3

FIGURE 3. DIMENSIONS AND LIGHT DISTRIBUTIONS FOR ROOM A-4

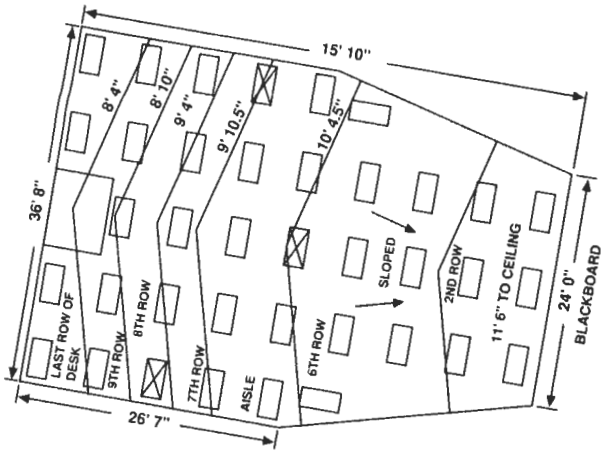

FIGURE 3A. DIMENSIONS OF ROOM A-4

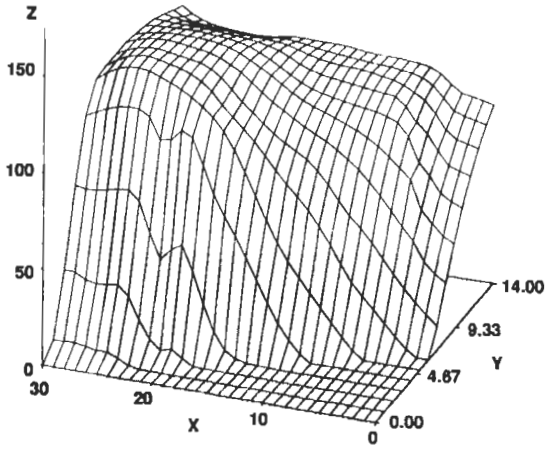

FIGURE 3D. NEW LAMPS
AVERAGE OF LIGHT LEVEL READINGS: 118.0

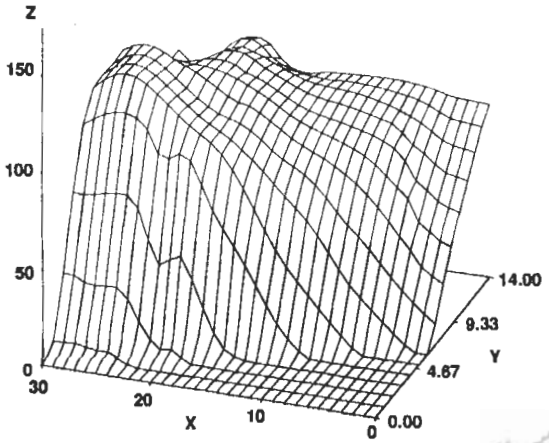

FIGURE 3B. AS-FOUND LIGHT LEVEL DISTRIBUTION

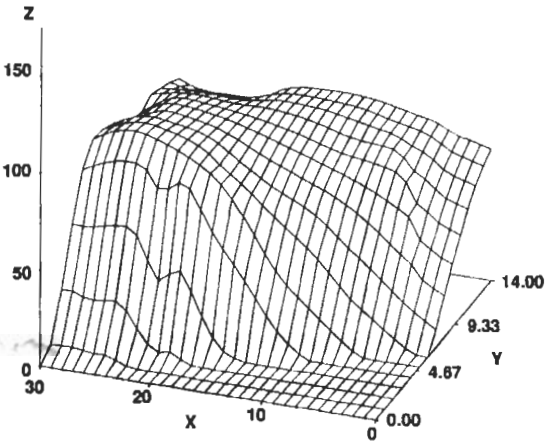

FIGURE 3E. DELAMPED AND REFLECTORS
AVERAGE OF LIGHT LEVEL READINGS: 88.6

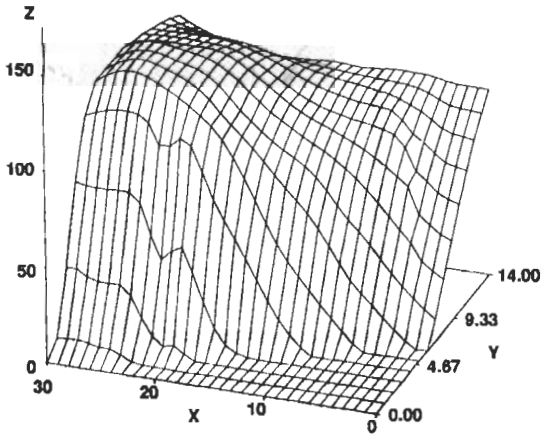

FIGURE 3C. CLEAN FIXTURES
AVERAGE OF LIGHT LEVEL READINGS: 107.0

FIGURE 4. DIMENSIONS AND LIGHT DISTRIBUTIONS FOR ROOM 22

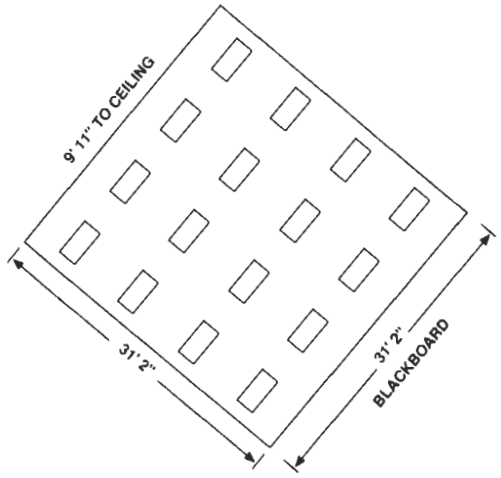

FIGURE 4A. DIMENSIONS OF ROOM 22

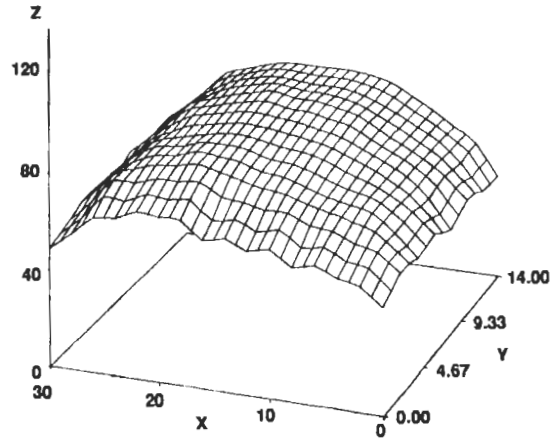

FIGURE 4B. AS-FOUND LIGHT LEVEL DISTRIBUTION
AVERAGE OF LIGHT LEVEL READINGS: 69.0

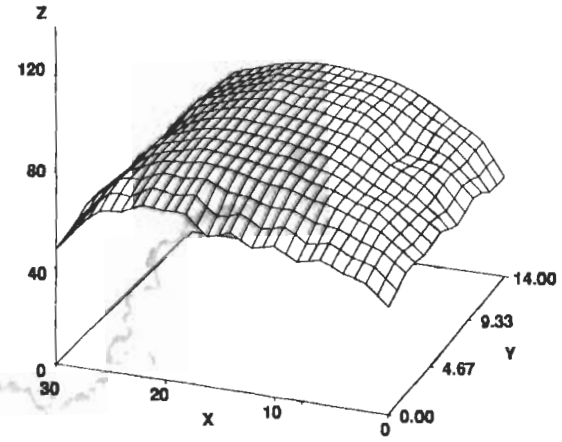

FIGURE 4C. CLEANED FIXTURES
AVERAGE OF LIGHT LEVEL READINGS: 69.7

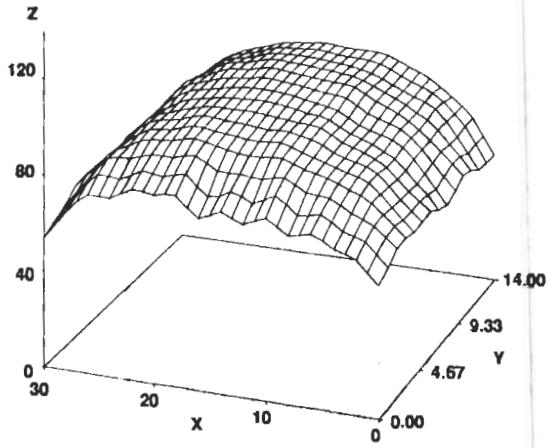

FIGURE 4D. NEW LAMPS
AVERAGE OF LIGHT LEVEL READINGS: 81.0

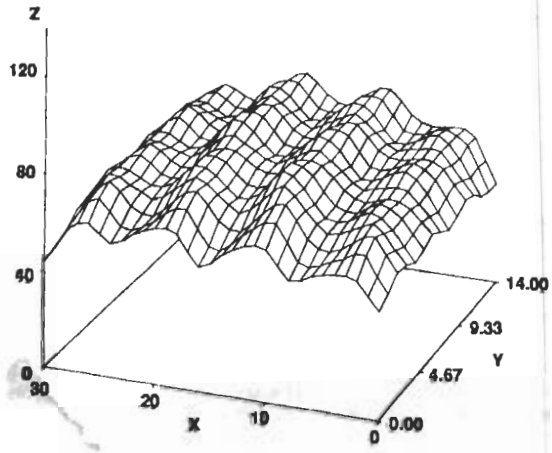

FIGURE 4E. DELAMPED AND REFLECTORS
AVERAGE OF LIGHT LEVEL READINGS: 64.7

Durability/Life. The test described in this paper does not make a statement concerning durability or life of the reflectors. Accelerated aging tests have been conducted on several specular reflectors and can be requested from the manufacturers. The quality of lamination will be a factor in reflector life independent of the quality of the silverized film. The effect of cleaning compounds and method of application (e.g., soft rag, sponge, brush) on the reflector surface should also be considered. See "Epilogue" below for more comments on durability.

Appearance/Performance Tradeoff. Reduced light levels may very well be satisfactory when the energy savings are considered. Delamped fixtures with reflectors typically look fully lamped. Glare on computer screens tends to be reduced.

Reflector Design/Materials. Specular reflectors are typically of two classes: rear reflective and front reflective. Manufacturers claim a difference in reflectivity. This test did not attempt to differentiate between the two. Additionally, reflectors are available with other surface finishes such as polished or anodized aluminum. Reflectors can also be specifically configured for each fixture and, for a given fixture, can be fabricated for narrow light focus (useful for aisle ways) or a wider pattern. The Beulah School reflectors were rear reflective and the Augusta College reflectors were front reflective. Both were fabricated for a wide pattern light focus.

Age of Fixture/Lens. Older fixtures and lenses will operate at lower efficiencies due to dirt and degradation compared to newer ones employing improved designs and materials. Older, deeper fixtures would seem to be the better candidates for retrofit with reflectors. The ages of the fixtures and lenses and the date of the most recent cleaning were unknown for all rooms.

Fixture Type/Height/Spacing. The fixture type, height and spacing may reduce the applicability of this light-level survey to rooms at other locations. Fixtures arranged in continuous rows, however, seem less suitable for reflectors because less light is distributed to the extremities of the room and between rows, resulting in greater room light-level variations. Rooms with greater fixture mounting heights seem to allow for better distribution of light with less intensity variations across the room.

CONCLUSIONS

Accurate comparison of relative light levels when fixture reflectors are installed as an energy-saving measure depends on many factors, the most important being that clean fixtures with new lamps are used for light-level measurements both before and after reflector installation. For the four rooms included in this study, cleaning the fixtures and installing new lamps increased light level measurements in the rooms by 10 to 22 percent. The fixtures in the four rooms were well maintained and, therefore, the increase in light levels attributable to cleaning and relamping are probably conservative.

Based on the limitations of this field test (see preceding section) the installation of specular reflectors in existing fixtures and the removal of half of the lamps and ballasts will reduce light levels to 60 to 80 percent of the clean, fully-lamped fixture light levels in good applications. Claims made by reflector vendors and manufacturer representatives that reflectors can increase light levels while saving 50 percent of the lighting energy bill are unfounded if design light levels are to be maintained.

Specular reflectors tend to concentrate the light beneath the fixture and leave somewhat darker areas between rows of fixtures and along walls. This effect is considerably less pronounced in rooms with high ceilings and evenly spaced fixtures. Only after careful study and consideration should reflectors be installed in rooms with fixtures in continuous rows and with low ceilings.

Specular fluorescent fixture reflectors are recommended as a means to reduce lighting energy consumption where lower light levels are acceptable. Where light levels are already marginal, reflectors should not be installed without some means of first increasing fixture light output.

EPILOGUE

The question of specular reflector durability has remained on the minds of many, including the author. Conversations in the second quarter of 1989 with personnel from four institutions having reflector installations from two to four years old gave some interesting insights. They include a bank, a department store, a hospital and a government health facility.

All contacted personnel were pleased with the light levels and none had seen any signs of delamination or bubbling of the reflective film. Scratches on the reflectors caused by fingernails and tube pins were noted in one instance. Unfortunately, none of the facilities have cleaned the reflectors and none have taken light level readings that compare design light levels with those after reflectors were installed or with current light levels. The only light level readings available are those made by the vendors of as-found levels and light levels after the installation of reflectors.

Concerned that these four facilities all represented success stories, the author called a high-level manager of a large fixture manufacturer. (The manager had authored a technical brief several years ago raising questions regarding the durability of reflectors.) When asked for misapplications or problem installations (specifically delamination and bubbling) he was unable to name any. It would appear that reflectors have considerably more satisfied customers than dissatisfied ones.